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Virtual Environment And Computer-Aided Technologies Used For System Prototyping And Requirements Development

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ABSTRACT

The Space Station Freedom (SSF) Data Management System (DMS) consists of distributed hardware and software which monitor and control the many onboard systems. Virtual environment and off-the-shelf computer technologies can be used at critical points in project development to aid in objectives and requirements development.

Geometric models (images) coupled with off-the-shelf hardware and software technologies were used in The Space Station Mockup and Trainer Facility (SSMTF) Crew Operational Assessment Project. Rapid prototyping is shown to be a valuable tool for operational procedure and system hardware and software requirements development.

The project objectives, hardware and software technologies used, data gained, current activities, future development and training objectives shall be discussed. The importance of defining prototyping objectives and staying focused while maintaining schedules are discussed along with project pitfalls.

1.0 INTRODUCTION

The Crew Task Assessment project started in the spring of 1991 as a proposal to the Flight Crew Support Division (FCSD) for a UNIX based computer system for the Space Station Mockup and Trainer Facility. This facility (see figure 1.0) is used for Space Station Freedom design development and for instructor and crew training. The prime objective is to construct an Operator Interface System that can be used to develop and evaluate SSF user interfaces. The secondary objective is to demonstrate the human-computer interface of the SSF Data Management System and use the system for instructor and crew training.

A three monitor UNIX X Windows workstation with SSF user interface viewing capabilities was completed in the summer of 1991(see figure 1.1). In the fall of 1991 sensor and transducer control was added to the system with off-the-shelf programmable logic controllers and in the early summer of 1992 data, video and control connections to the Graphics Analysis Facility (GRAF) were added. In the fall of 1992 robotic hand controllers where added. The system presently has SSF onboard display viewing, SSF and Space Shuttle camera images and control, and SSF and space shuttle robotic image and control capabilities.

As our knowledge increased and equipment came on line, the objective expanded to rapid prototyping. Today our objective is to have hardware, software, graphics, and interface capabilities to do rapid (less than 1 month) prototyping for SSF DMS related development. These computer and graphics capabilities coupled with the Mockups and Trainers give us the tools to assist in design, writing requirements and specifications and verification of man-machine interfaces.

2.0 SETTING OBJECTIVES

Our main objective was to choose hardware and software which could be used to emulate flight systems early in the program to assist requirements development. This system would be used to give future users a chance to evaluate and comment on the proposed flight systems in time for changes. The hardware and software is off-the-shelf and required no video drivers or kernel programming. For each project or task the customers, users and stake holders are defined. The success of the task is also defined. The original startup project success definition was:

> A UNIX based computer system in the SSMTF which will run SSF onboard displays in a flight like environment. These displays shall have process control and monitoring capabilities. The system shall provide positive crew and user training. The system shall be built with off-the-shelf components and software. The system shall be in operation by the summer of 1992.

The original customer definitions were:

USER/CUSTOMER	TASK
Space Station Reconfiguration Office	display reviews and requirements development
Crew Office	crew task assessments.
Human Computer Interface Lab	display standards development and review
Mission Operations	training development.

Today the objectives have expanded to address the following:

- Direct Views: of assembly and maintenance tasks by IVA crew
- External Lighting: for direct and video views
- Visual Cues: alignment aids and targets
- Displays: procedures, data, video views, communications, graphics needed to perform tasks at the workstation
- Workstation Design: anthropometry of workstation and hardware switches, controls arrangement, adequacy of task lighting
- Functionality and operability of robotic controls

3.0 EXAMPLE EVALUATIONS

Following are two examples of ongoing evaluations being performed in the facility. Over five evaluations have been held to help define workstation and flight display requirements.

3.1 CREW OPERATIONAL ASSESSMENT OF SSF WORKSTATIONS

A Crew Operation Assessment of Space Station Freedom Workstations was performed in February 1993. The objective of this assessment was to define the off-screen requirements for camera and robotic controls. The test scenario was a robotic operation, as planned for Utilization Flight 1 (UF-1). The operations involved controlling the Space Station Remote Manipulator System (RMS) in manual mode, automated mode and single joint mode. Grappling, maneuvering and berthing actions were accomplished, simulating Cryo Carrier Installation tasks. The Command and Control (C&C) workstation (see figure 1.1) in Node 1 was used to simulate operations in a Node or Cupola. All displays were Space Station prototypes. They included several shuttle arm displays, Communication & Tracking, Camera Configuration and Camera Control displays, and text procedure viewers. Figures 3.0 and 3.1 show typical display scenarios.

Thirteen cameras were available for evaluators to use throughout the scenario. Manual control panels were mounted on the workstation rack front face. Thirteen camera views were programmed at the GRAF lab. These views had pan, tilt, and zoom capabilities with keyboard, on-screen (computer mouse) or off-screen (key board or manual panel) control and selection. Split screen capabilities (two views sharing one NTSC window) could also be selected. Arm motion was simulated using predefined positions selected from the keyboard because the hand controllers were not operational at the time. Off-screen and on-screen control of the space shuttle arm brakes, auto sequence controls, and single joint controls were also available.

The operational scenarios evaluated contributed to the recommendations made for workstation features and capabilities. Figure 3.2 gives the overall view of the SSF in the Man Tended Configuration (MTC). It shows some of the camera positions used in camera viewing and control evaluations. Figures 3.2 through 3.10 show Shuttle and Space Station camera views, as seen at the workstation, during robotic arm operations. Figure 3.4 shows a Space Station truss camera view of the stowed shuttle and Space Station arms. Figures 3.5 through 3.8 show the shuttle and Station views required to grapple a payload in the Shuttle payload bay and move it to the Space Station arm. Figures 3.9 and 3.10 show the payload hand off using shuttle payload camera C and the Node camera. Users selected and controlled the 13 cameras to decide the best viewing for grapple, payload hand-off, and docking.

The results of the evaluation are detailed in "CREW OPERATIONAL ASSESSMENT OF SSF WORKSTATION" distributed by the Station-Exploration Support Office in April 1993.

3.2 DISPLAYS AND CONTROLS MODE TEAM CREW EVALUATIONS

The Displays and Controls (D&C) Mode Team's primary responsibility is to develop and document in the D&C Flight System Software Requirements (FSSR) the requirements for on-board displays. The SSMTF facility is being used to develop and evaluate displays. The virtual environment created using the GRAF camera images has contributed to the development of flight menus for camera control and on and off screen controls. The simulated robotics displays and images coupled with functional hand controllers and camera views can be used to develop flight robotic displays and controls, and for training.

Figure 3.11 is the Main Menu of the flight user interface. The Communication and Tracking (C&T) display tree takes you to the Video Configuration display figure 3.12. This display is used to power cameras up and down and to make initial camera to monitor connections. The display used for camera control is shown in figure 3.13. When the camera control display is opened the keyboard gains camera control functions. Camera images can be panned, tilted, and zoomed from the arrow keys on the keyboard. Camera selection can also be made using the keyboard. The camera control displays coupled with the Shuttle arm and Space Station arm displays, figures 3.15 and 3.16, are used to control the robotic arms in a virtual environment in the SSMTF. The robotic control and camera selection and control commands come from the SSMTF computers and interfaces. This control information drives the GRAF image generation. The images are converted from RGB to NTSC format and sent to the SSMTF for display.

4.0 SYSTEM SOFTWARE

4.1 SPACE STATION MOCKUP AND TRAINER FACILITY

The User Support Environment (USE) prototyping activities during 1990 identified Kinesix Corporation's "SAMMI" product as the display build and display execute product for the SSF onboard displays. SAMMI is a Graphical User Environment for building X Window based user interfaces for managing networked information systems. The networked systems in the SSMTF project include:

Command and Control Workstation
Cupola Workstation
Development workstation in the computer lab
Programmable logic controller
PC in lab
Silicon Graphics machines in the Graphics Analysis Facility

4.1.2 COMMUNICATIONS

The Workstation to GRAF software is shown in figure 4.0. Remote Procedure Calls (RPCs) are used between the SAMMI run time display code and applications and/or data bases run locally or on a remote machine/s.

Ethernet and TCP/IP is used to connect all computer based CPUs. Control panels and hand controllers are connected to programmable logic controllers (PLCs). These controllers have plug and go input/output boards for interfacing control wiring to a CPU.

The programmable controller uses a "remote I/O protocol" to communicate ladder logic program information to the PC. PLC I/O data tables are mirror imaged on the PC. Using FTP INC. and Allen-Bradley libraries a C program transfers the PLC information to the UNIX workstations, or vice versa. The UNIX data base is a mirror image of the PC data base.

Workstation displays interact with a data base running locally, or remotely, using an application program interface (API) and Remote Procedure Calls (RPC). Examples of application interfaces running in the SSMTF which provide display to data base connectivity are:

Camera control API	peer to peer: display to PLC and display to GRAF control information
Robotic control API	peer to peer: display to robotics model model to PLC, model to GRAF
dp4ndbm	client-server: polled data base

Figure 4.1 shows the data flow from the three computer environments: SUN, Silicon Graphics machine in the GRAF, and the programmable logic controller with personal computer.

4.1.3 HAND CONTROLLERS

Robotic hand controllers are connected directly to the PLC analog input ports. The PLC sends a digital number to the PC data base for each of the six hand controller motion commands and three hand grip switches. The data base of motion and switch status commands, located on the PC, is read by the workstation robotic model. The robotic model process sends position and status information to the workstation data base which streams the information to the display.

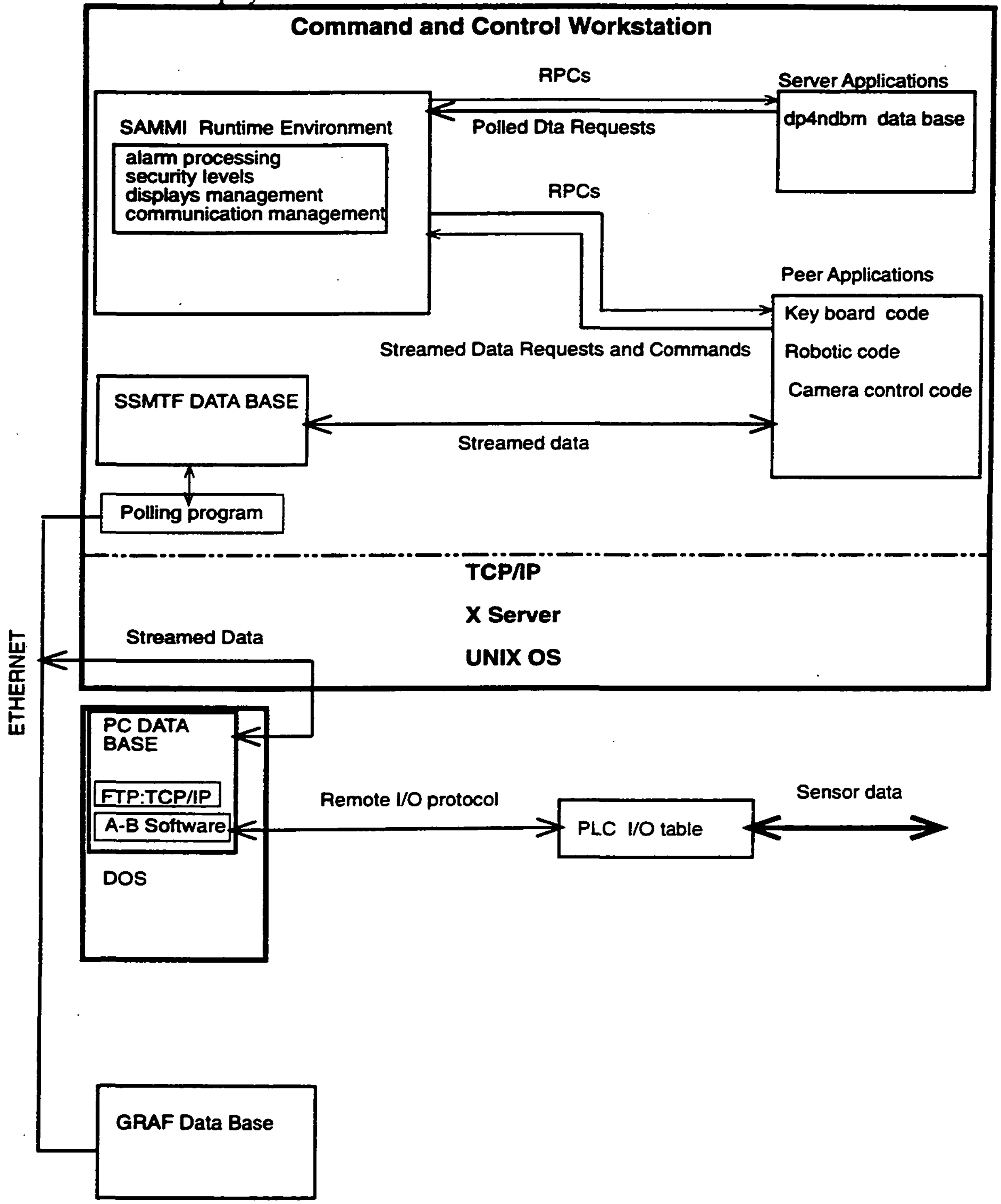


Figure 4.0 SSMTF Software Overview

Fig. 4.1 = 366p

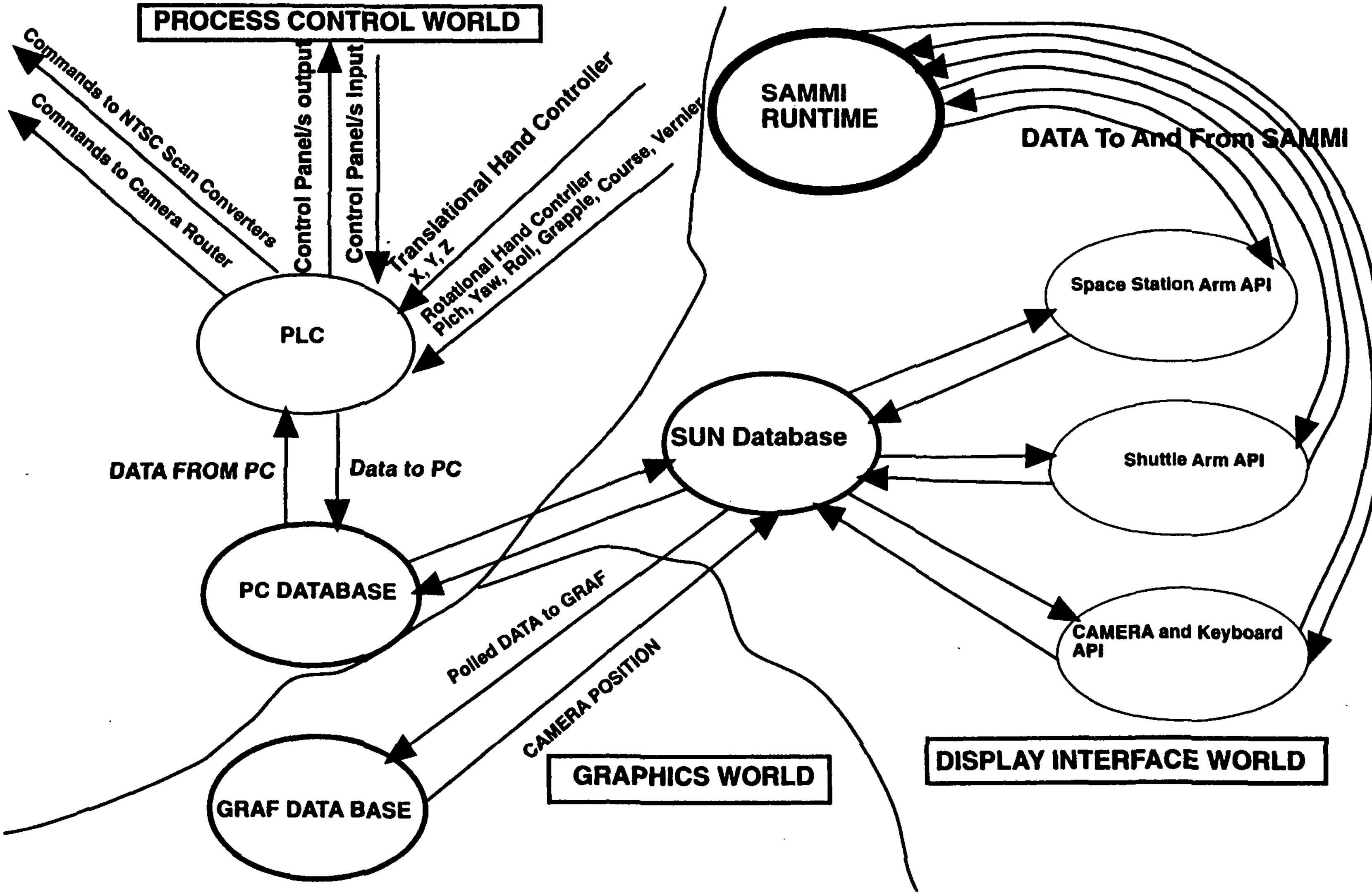


Figure 4.1 SSMTF Software Data Flow
366

The joint angles calculated in the robotic model are sent to the GRAF for robotic graphic model manipulation. It should be noted that a polling program, running on the UNIX machine with the data base, checks for changes in the data base before sending the data file to the GRAF. This reduces network traffic.

4.1.4 CAMERA CONTROL

Camera control and selection can be done using the SAMMI display, keyboard, or manual control panel. Command information is sent to the GRAF from the data base running on the workstation. The difference is how the data base is manipulated. The hard control panel communicates through the PLC, the keyboard through an X-window server based API, andthe SAMMI display through a SAMMI based API.

4.1.5 NTSC SCANNER CONTROL AND CAMERA ROUTING CONTROL

The PLC has an ASCII Basic card which outputs RS 485 commands given input from the PLC I/O table. This RS 485 command is used to control the camera router and NTSC scan converters.

4.2 GRAPHICS ANALYSIS FACILITY

The synthetic camera views shown on workstation monitors in the mock-ups are produced on two Silicon Graphics Reality Engines in the Graphics Analysis Facility (GRAF) in Building 15 and conveyed to SSMTF in Building 9 via coaxial cable. So far, each SGI workstation has been used to produce the images for one monitor, but special video-splitter hardware installed in the workstations enables each Reality Engine to produce images for up to three monitors.

The software which produces the camera views consists of two programs, one of which runs on the SGI workstation and the other on the Sun workstation used for the Sammi system. The program on the Sun treats the Sammi files as read-only and polls them every tenth of a second. It extracts camera commands from the PLC records and shuttle arm commands from the Sammi data base. If any of the camera or robotic arm control variables have changed since they were last polled, a command record containing the current data is sent to the SGI workstation via the Internet. Traffic on the network is minimized by transmitting only when a variable has changed. Except for small acknowledgment records sent back to the Sun, all information flow is one-way. The communication is carried out via Berkeley sockets using the TCP/IP protocol.

Two copies of the polling program run on the Sun workstation, one to communicate with each SGI workstation. Whenever a change occurs in a relevant data base or PLC variable, each polling program detects it and sends the appropriate commands to its SGI workstation. Thus, even though the programs running in the two SGI workstations do not communication with one another, their representations of the camera and robotic arm positions remain identical because they both see the same sequence of commands.

The program running on the SGI workstation consists of two processes, one to handle the communication and the other to draw the images. Using a separate process to handle communication guarantees that no command record is ever lost, even if it is sent while an image is being drawn. It is possible for several command records to arrive while an image is being drawn; the effects of the commands are accumulated until they can be carried out by the drawing process.

The drawing process runs the GRAF's in-house display program, DMC, augmented with a special interface to allow it to interpret the commands received over the network. The interface reads the accumulated network commands and turns them into DMC commands, which it issues to DMC. If any command could have caused a change in the image, the image is redrawn. In order to handle the split-screen feature of a simulated monitor, the display is divided into two viewports; if only one viewport was changed by the commands, only that viewport is redrawn. (Likewise, when one workstation is used to simulate multiple monitors, the display is divided into multiple viewports, and only the affected viewports are redrawn.) Software clipping and polygon meshing were added to DMC to increase its drawing rate for this application.

Redrawing is not begun until a half-second's worth of camera motion has been accumulated, so that a redraw is not wasted on an undetectable amount of motion. (If the motion command is terminated before a half-second, it is performed immediately.) While image-changing actions are in progress, the display is redrawn as often as possible. The redraw time causes camera and arm motion to appear to occur in increments rather than smoothly. However, the total affect of the motion is accurate, as if it had been performed continuously.

The two processes in the SGI program are implemented as so-called light-weight processes, sharing memory space. Their access to shared variables (the accumulated commands) is controlled by means of semaphores.

5.0 SYSTEM HARDWARE

The major hardware components in the SSMTF are shown in figure 5.0.
They are:

Three monitor UNIX 486 PC Cupola Workstation
Three monitor UNIX 486 PC Node Command and Control Workstation (CCWS)
Three monitor SUN Lab Workstation
386 PC with Ethernet card and Allen Bradley programmable logic controller (PLC) scanner card.
Programmable Logic Controller (PLC) with various I/O boards and ASCII basic Card
Hand controllers
keyboard, track ball
manual camera control and robotics control panels
NTSC to RGB scan converters
RS-485 to RS-232 smart node boxes.
video router and cameras

5.1 CONTROL SIGNALS TO UNIX

The software available off-the-shelf drove the hardware purchases. The requirement most difficult to satisfy was the I/O to UNIX interface. A solution was found using a PC, an Allen Bradley scanner card, and an ethernet card. (PLCs are now being made with a direct ethernet connection and RPC/streams development software giving a more elegant solution). The PLC, PC, and UNIX workstation have communication connections. After the I/O to UNIX solution was found application interfaces were written between SAMMI and the PLC. Rapid prototyping of candidate control panels is achieved using PLC, I/O boards, scanner card, PC, and ethernet. In the latest review camera control and selection information from a manual panel was sent to the GRAF lab and images manipulated using the panel input.

5.2 THREE HEADED X TERMINALS USING PCs

The three monitor workstation is a three head 386 PC running UNIX and a three screen X-server. The PC was used because of its low cost. The Command and Control Workstation PC in the mockups is acting as a three monitor X terminal. The SAMMI displays, APIs, robotic model etc. are all running in the LAB.

5.3 NTSC VIDEO ON SVGA MONITORS

The second most difficult task was getting NTSC video in a movable, resizable, window, controlled by RS232, on a SVGA RGB monitor driven by a 386 CPU running UNIX and X. It was done using RGB Spectrum model 2050 boxes. The GRAF NTSC video is sent across site to the video router and the RGB 2050 boxes. The RGB 2050 boxes are controlled using RS232 ports, RS485 addressable boxes, and the ASCII basic card in the A-B PLC. SAMMI communicates to the data base, the PLC reads the data base and the ASCII BASIC card sends out a command frame over the RS485 network. The correct address acknowledges the command and acts. The RS 485 network is used to emulate the flight 1553 contol because of its low cost.

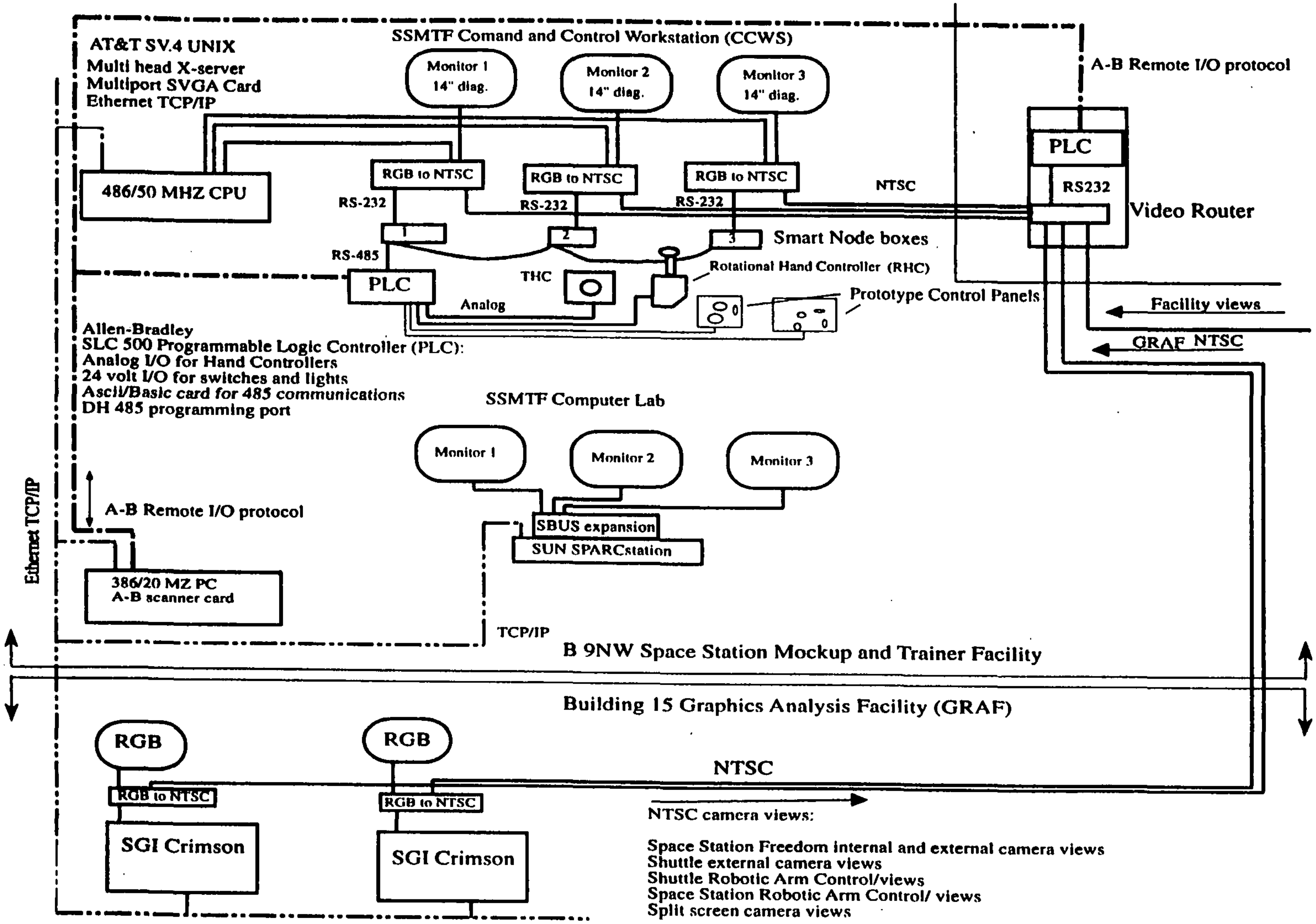


Figure 5.0 SSMTF HARDWARE OVERVIEW

5.4 CAMERA CONTROL AND SELECTION USING GRAPHICS

The camera selection is done on-screen using the camera control display push buttons (see figure 3.13). The peer to peer API between SAMMI and the PLC data base reads the button press event and a corresponding bit is set in the PLC data base. The polling program on the UNIX machine sends the data to the GRAF Silicon Graphics machine and the image is redrawn from the new camera's point of view. The pan, tilt, zoom functions act in much the same way with the keyboard key press and key release events being sent to the GRAF. A manual off screen control box can also be used to select and control cameras. One of the buttons on the manual control box sets a bit in the PLC data base. This set bit tells the GRAF lab that the of-screen control is activated. All camera selection and control commands are read from the off screen control box.

5.5 ROBOTICS USING GRAPHICS

In simple terms, shuttle arm hand controllers are connected to A-B analog cards. These cards feed a digital number to the PLC and UNIX math model. Software converts this delta position information to joint angles. These angles are read by the GRAF Lab and graphics are manipulated using the joint angle information.

6.0 LESSONS LEARNED

In the short time the system has had robotics and camera capabilities a few conclusions can safely be drawn:

1. Virtual environments can aid requirements development for man-machine and human computer interfaces.

2. Products like SAMMI are excellent tools for prototyping control panels/interfaces quickly. Users can test designs economically and with flexibility.

3. Mockup environments can be supplemented with virtual environments and computer technologies. Combining facilities and talents can give additional capabilities with improved asset utilization.

4. We learned that given scenarios such as the SSF camera control:

  - Possibly 20 or so cameras each with pan, tilt and zoom, power on/off, available/not available.
  - Three possible workstation destinations with three monitors each.
  - Three monitors at each workstation, two with split screen capabilities.
  - Camera selection and control capabilities from the computer screen and/or the key board and/or the manual control panel.

A quick working prototype will save many hours of writing requirements and meetings.
Users do not know 100% of their requirements. Give them something to help them decide.

5. In the computer world what you spend may not be proportional to the value of what you get.

6. If you build it they will come.

7.0 FUTURE PLANS

Voice control tests and more extensive display and camera control tests are being scheduled for the near future.

Real time UNIX software is being evaluated and multi headed X-servers developed.

The current capabilities give active hand controllers and screen refresh rates of approximately 1 second. Its hoped that Space Station software and hardware development groups will use the facility to test system and subsystem software user interfaces and control logic.

Facilities to measure CPU usage (Xstones, Whetstones, network impact) are being added.

As development engineering slows the facility will be used for crew training. All hardware was purchased with dual use in mind. The PC's and UNIX machines can be used in an office environment. The PLCs can be used to control the trainer mockup systems. The video equipment will be used in instructors stations.

As/if the Space Station is redesigned the GRAF facility can send the Space Station Mockup and Trainer Facility new images and evaluations can continue.

Figure 1.0 Mockup and Trainer Section

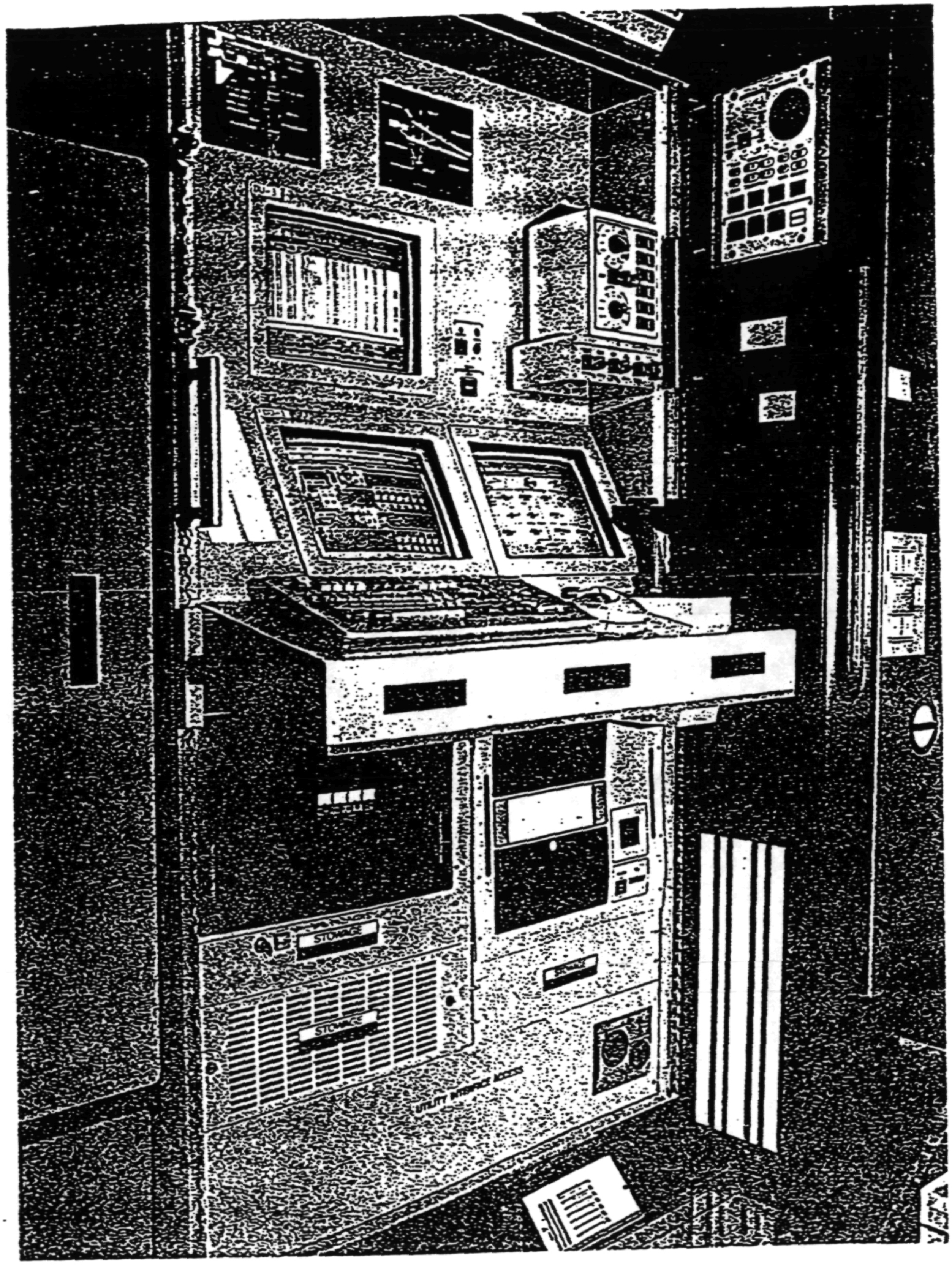
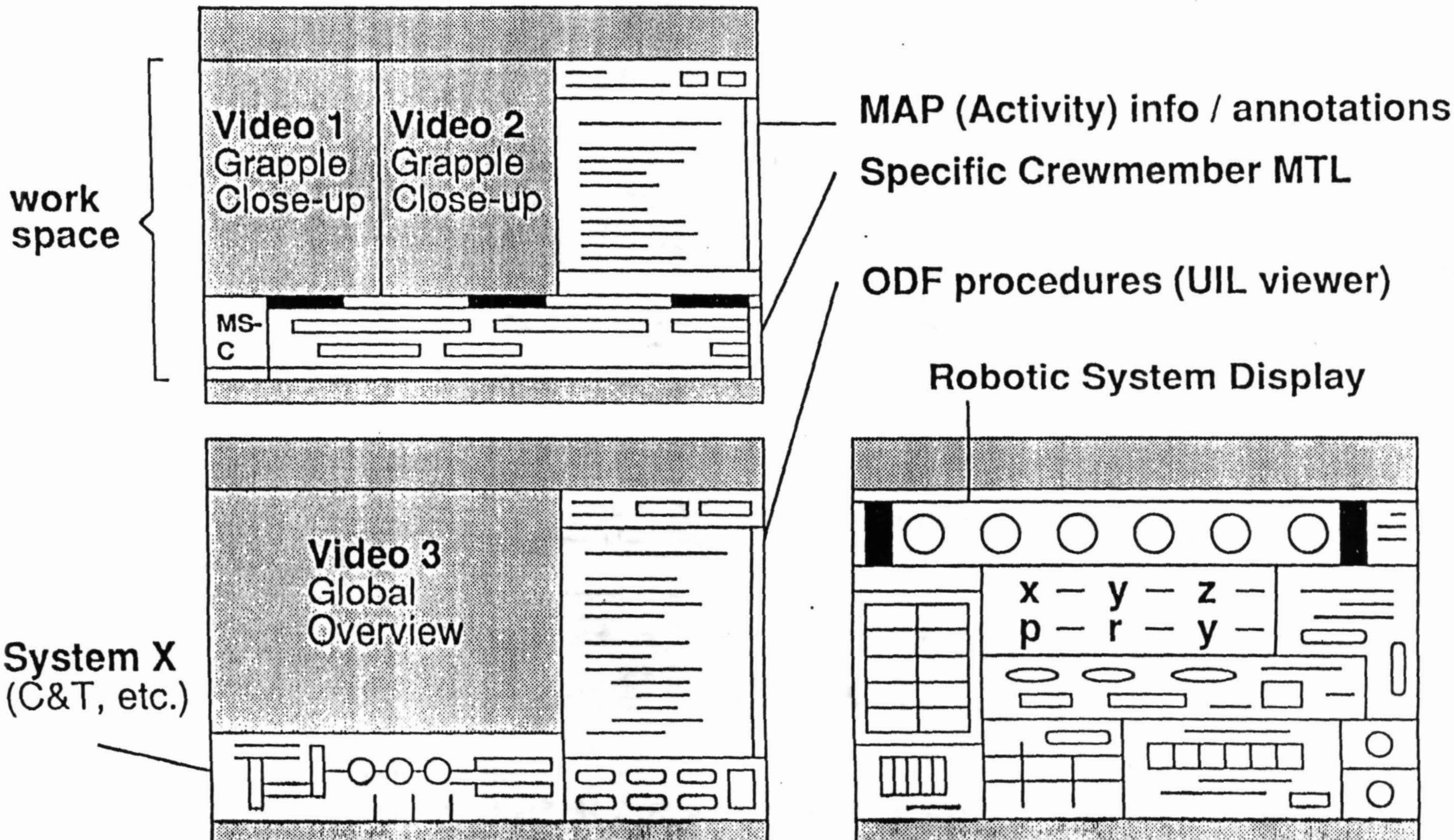


Figure 1.1 Mockup of Command and Control Workstation

ROBOTIC OPERATIONS
at U.S. workstation (3X14" Monitors)

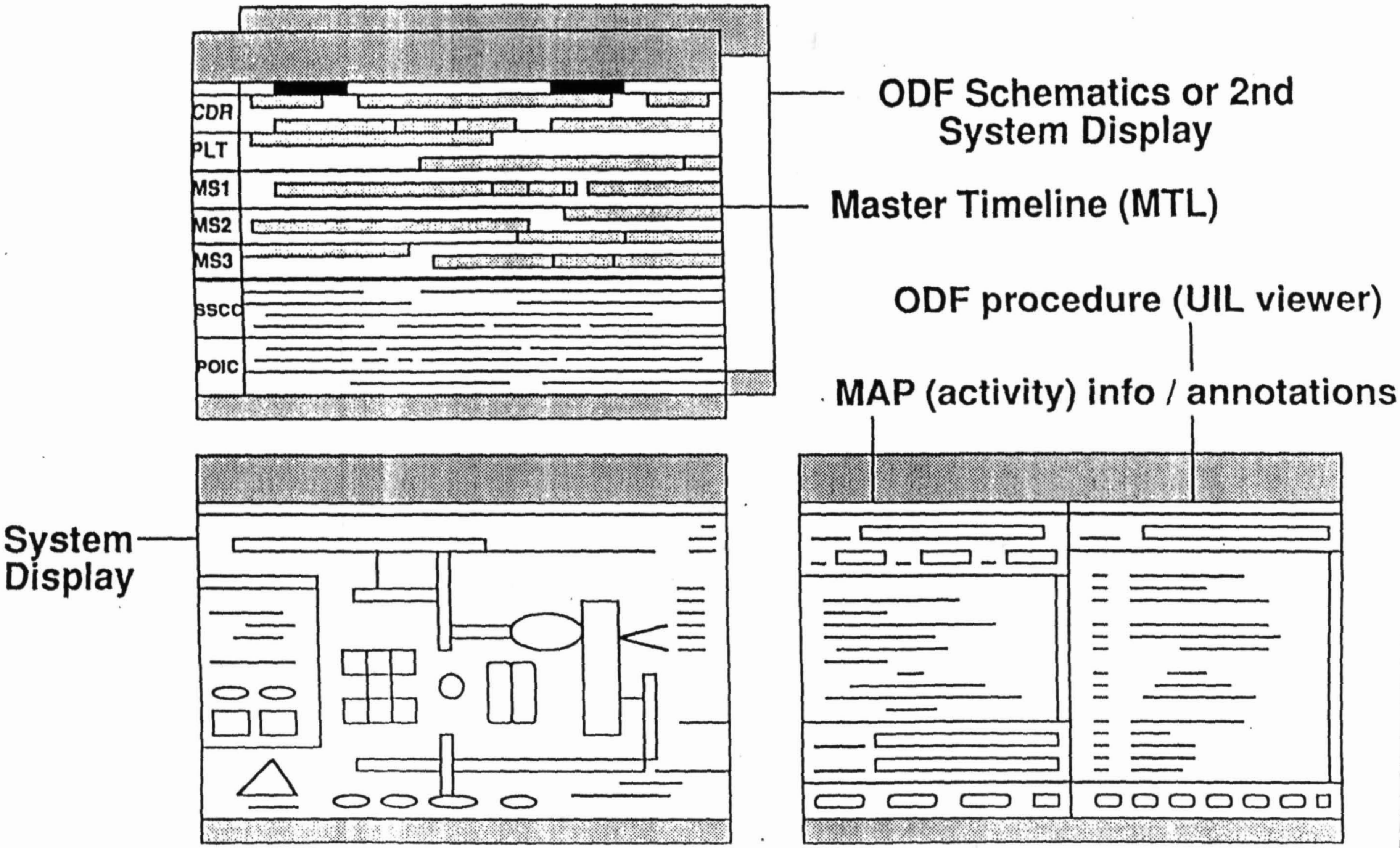


Int'l CSR, December, 1992

FCOD/CA3, Henk Prenger

Figure 3.0 Robotic Operations

SYSTEM OPERATIONS
at U.S. workstation (3X14" Monitors)



Int'l CSR, December, 1992

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Figure 3.1 System Operations

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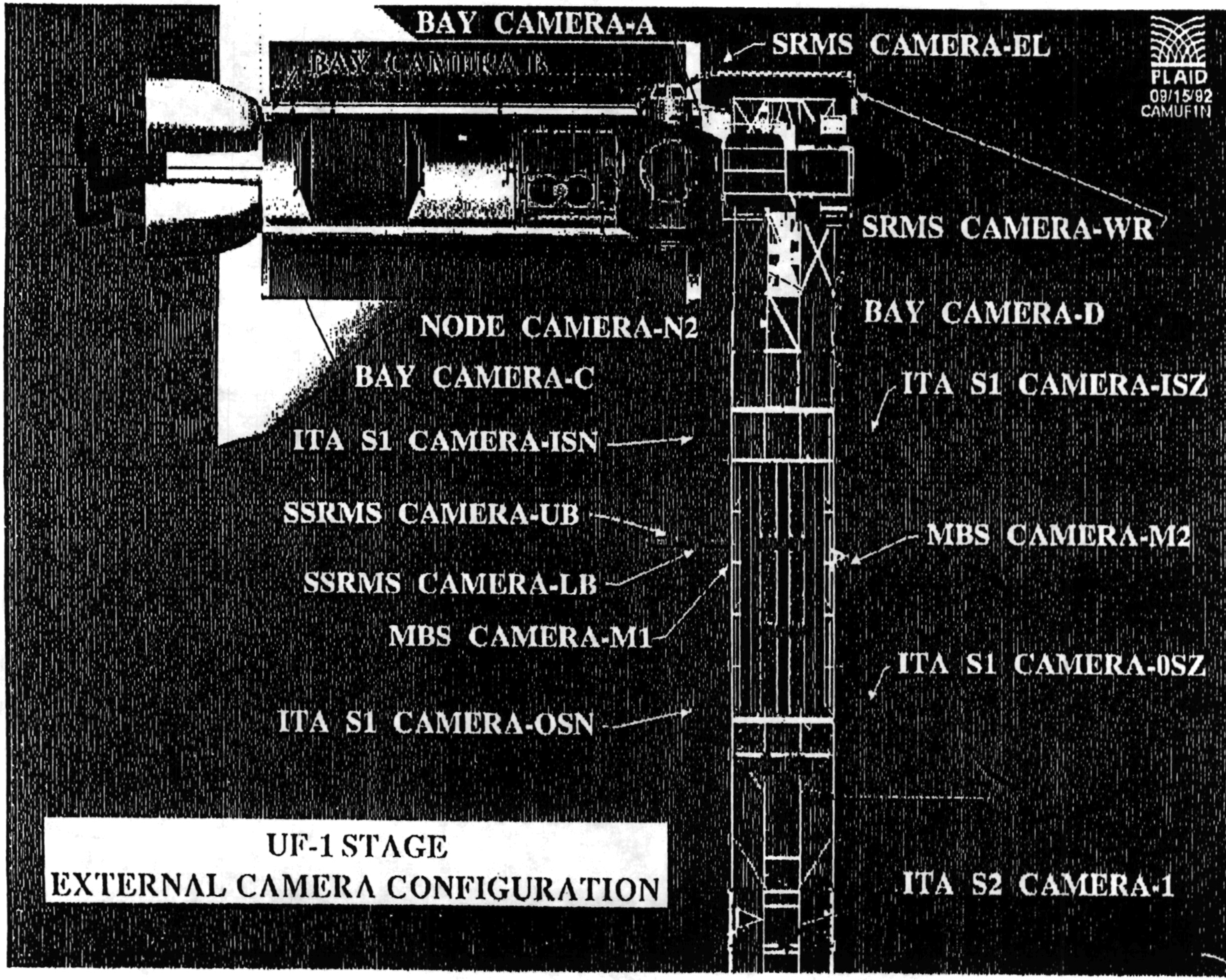

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Figure 3.2 Space Station, Man Tended Capability

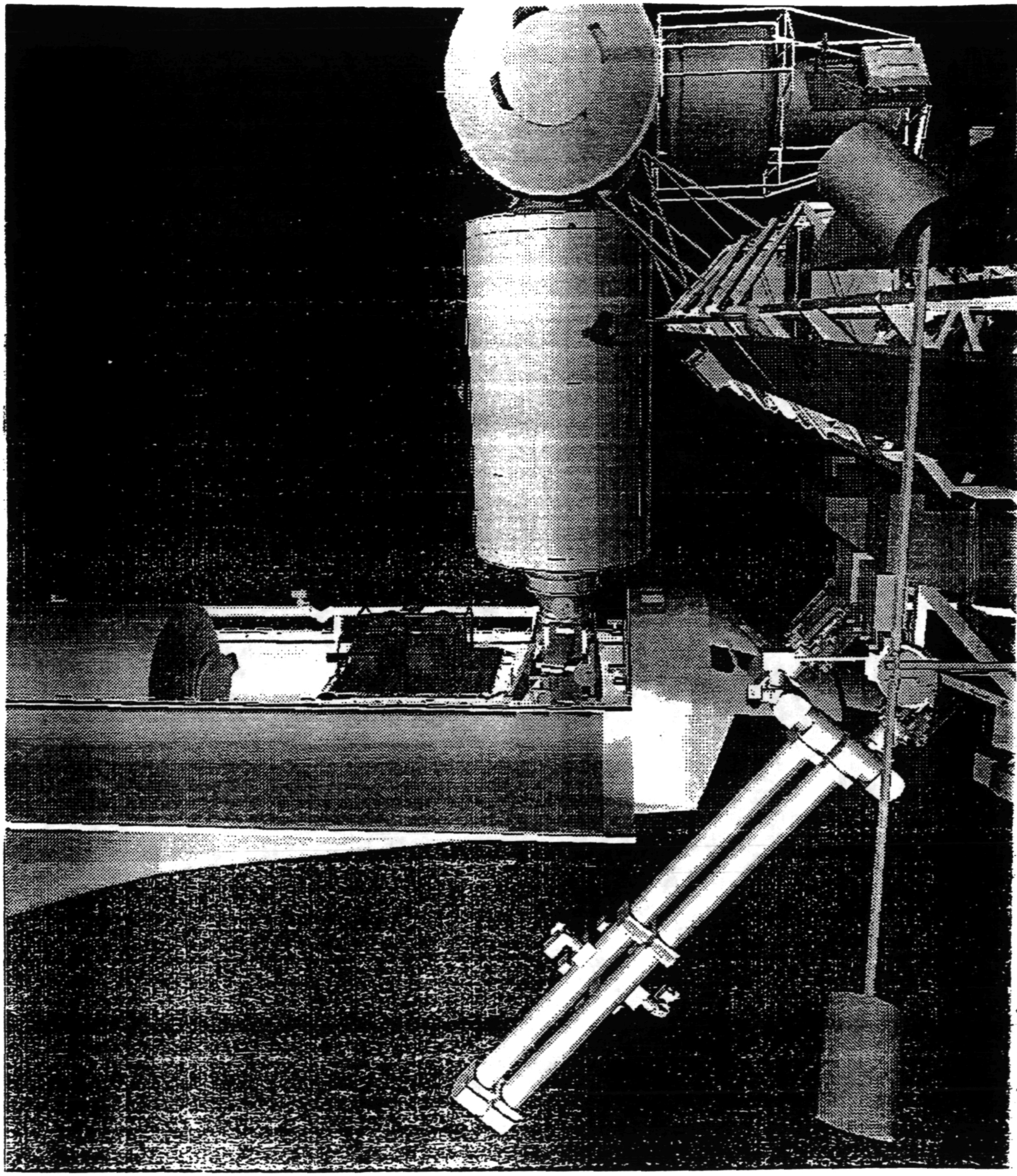

Figure 3.4 Space Station Outer Truss Camera View

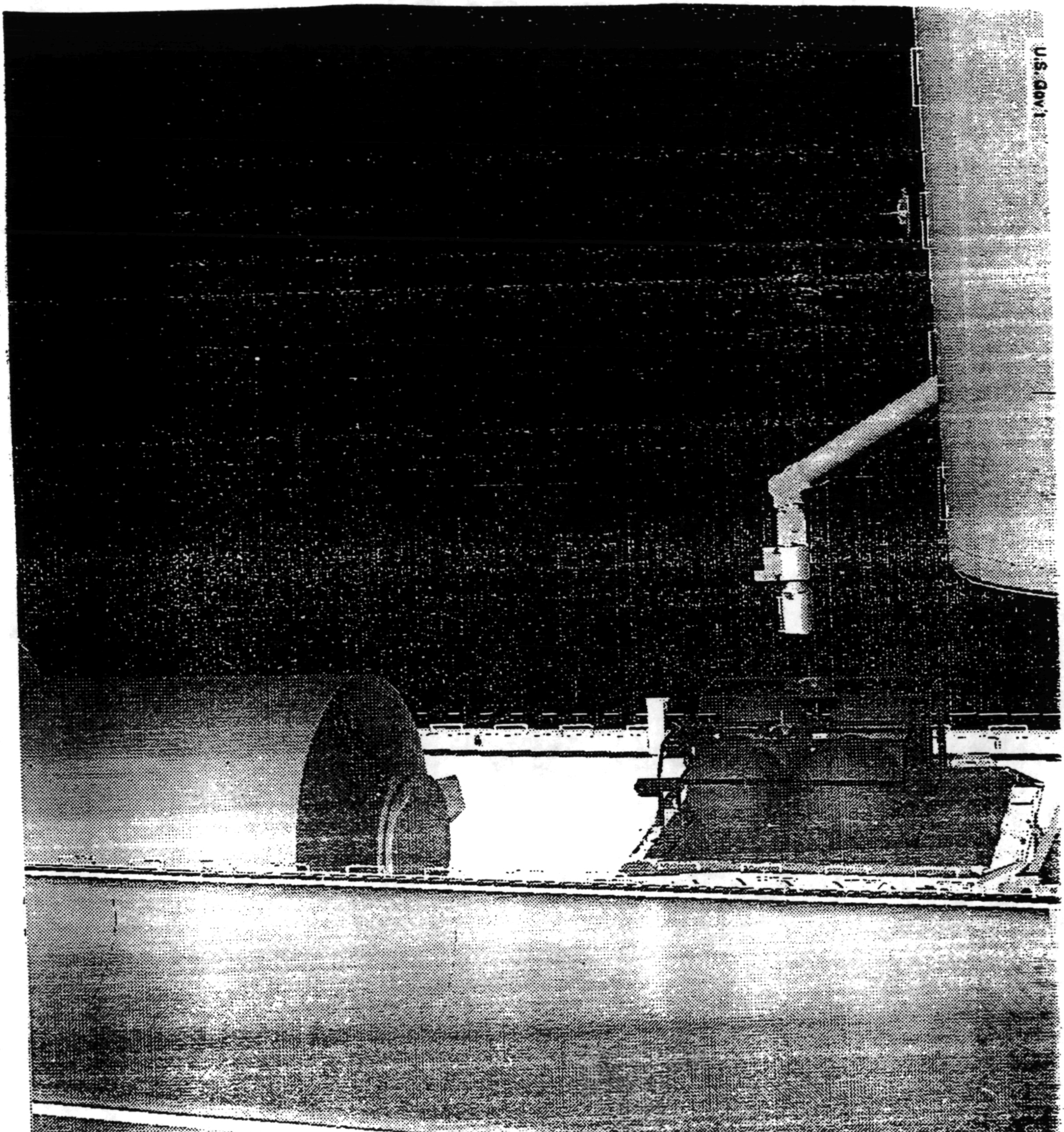

Figure 3.5 Space Station Inner Truss Camera View

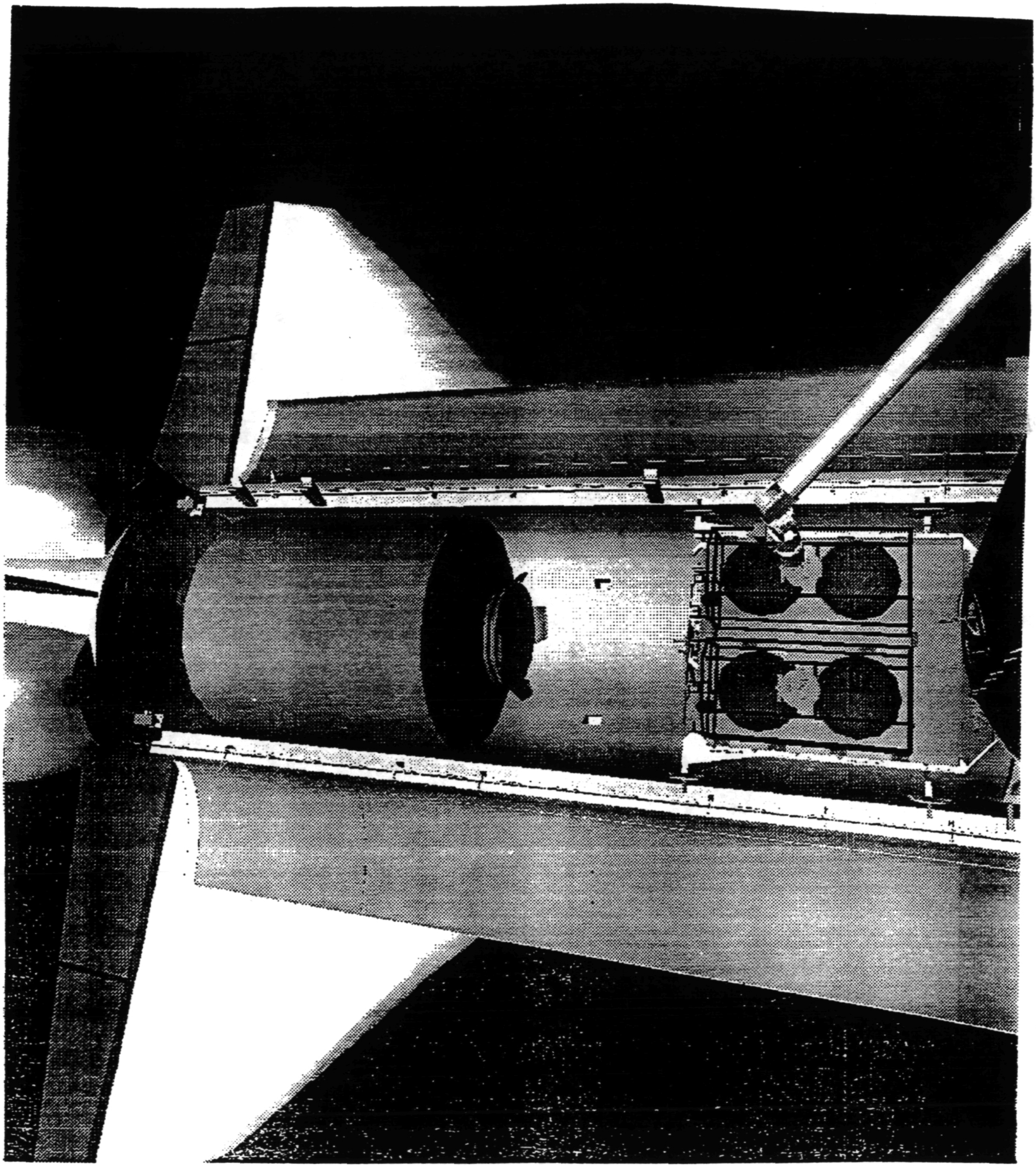

Figure 3.6 Node Camera View

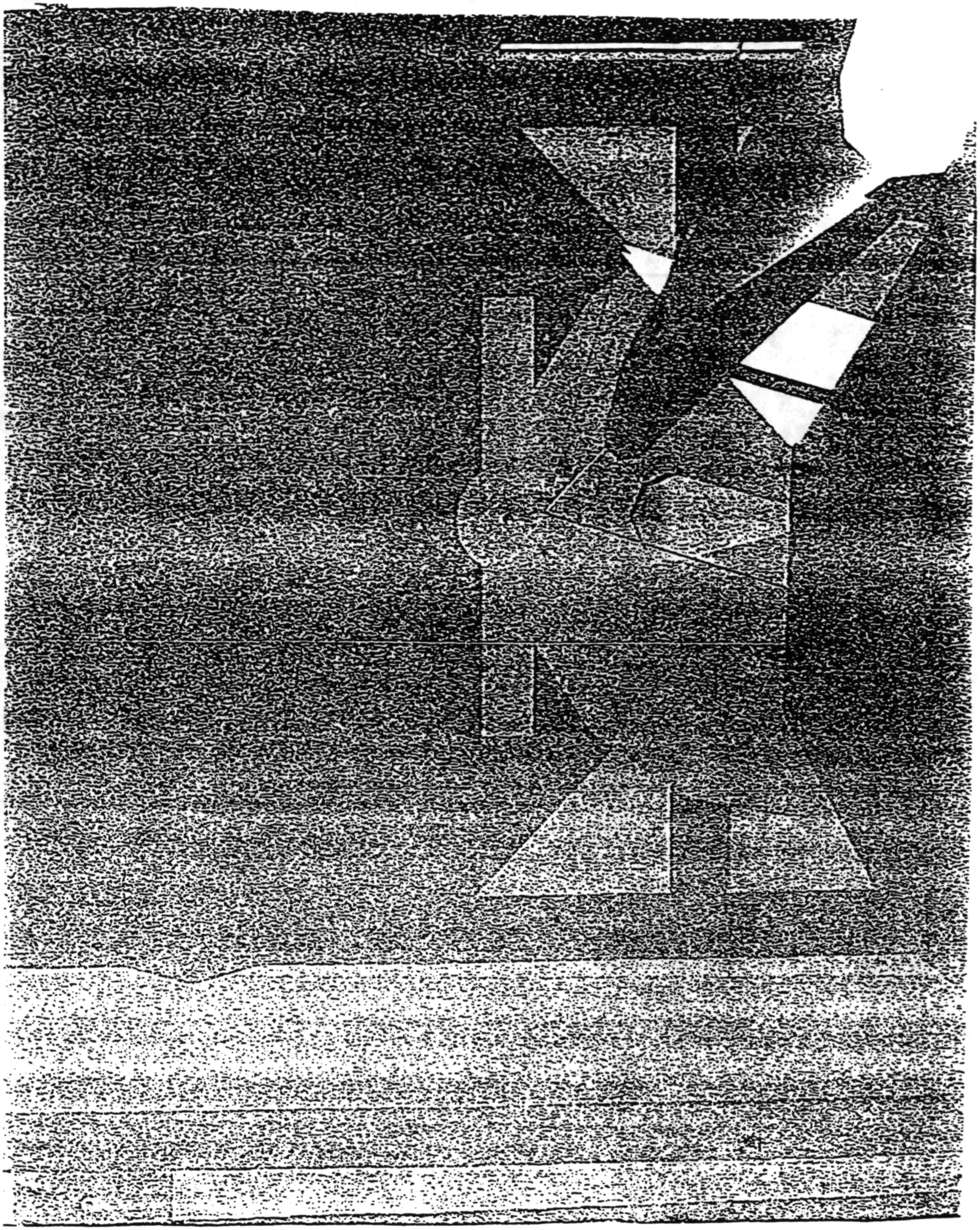

Figure 3.7 Shuttle Arm End Effector Camera View

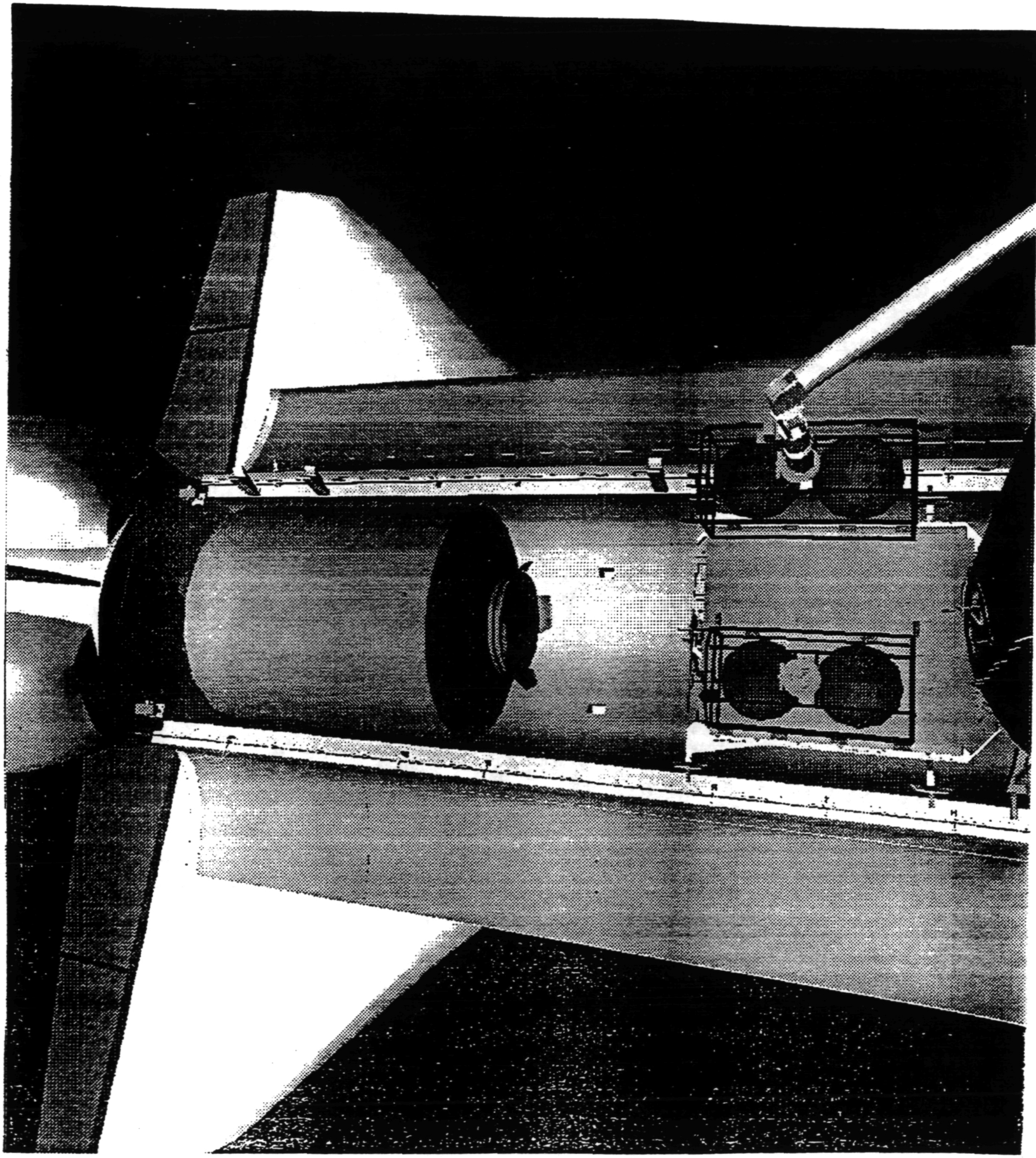

Figure 3.8 Node Camera View Showing Payload Movement

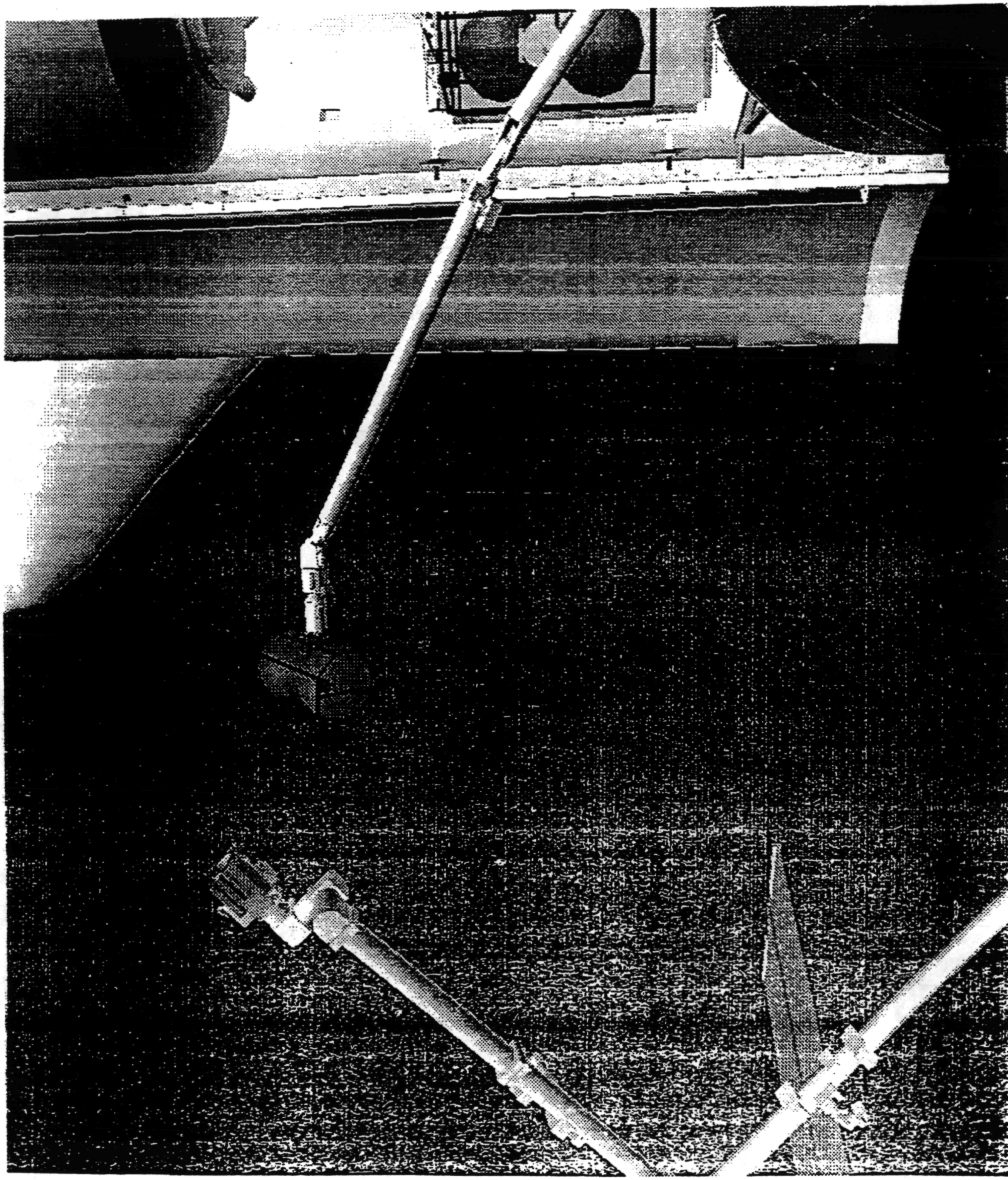

Figure 3.9 Node Camera Showing Shuttle Arm and Space Station Arm

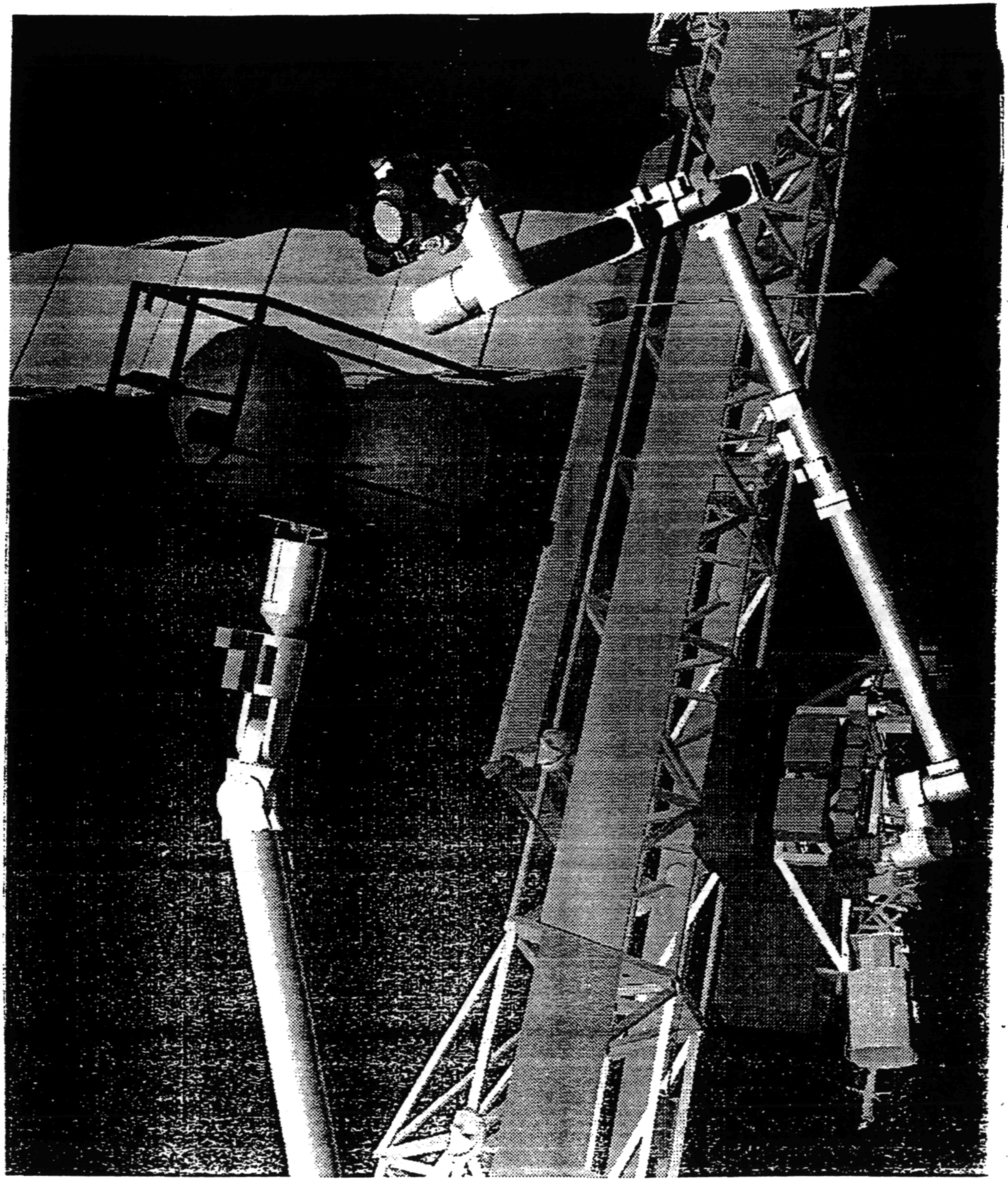

Figure 3.10 Shuttle Payload BayC Camera Showing Payload Handoff to the Space Station Arm

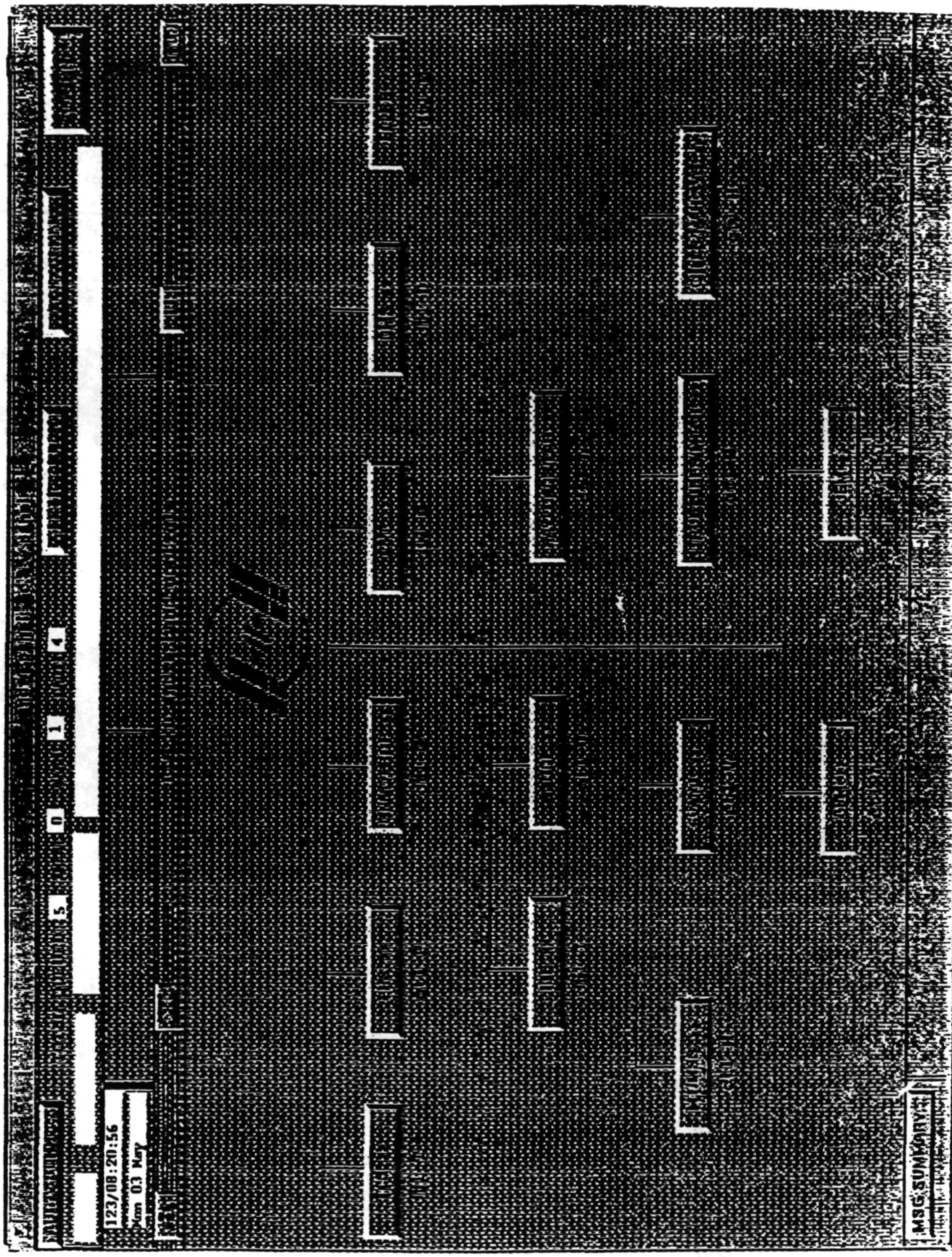

Figure 3.11 Main Menu

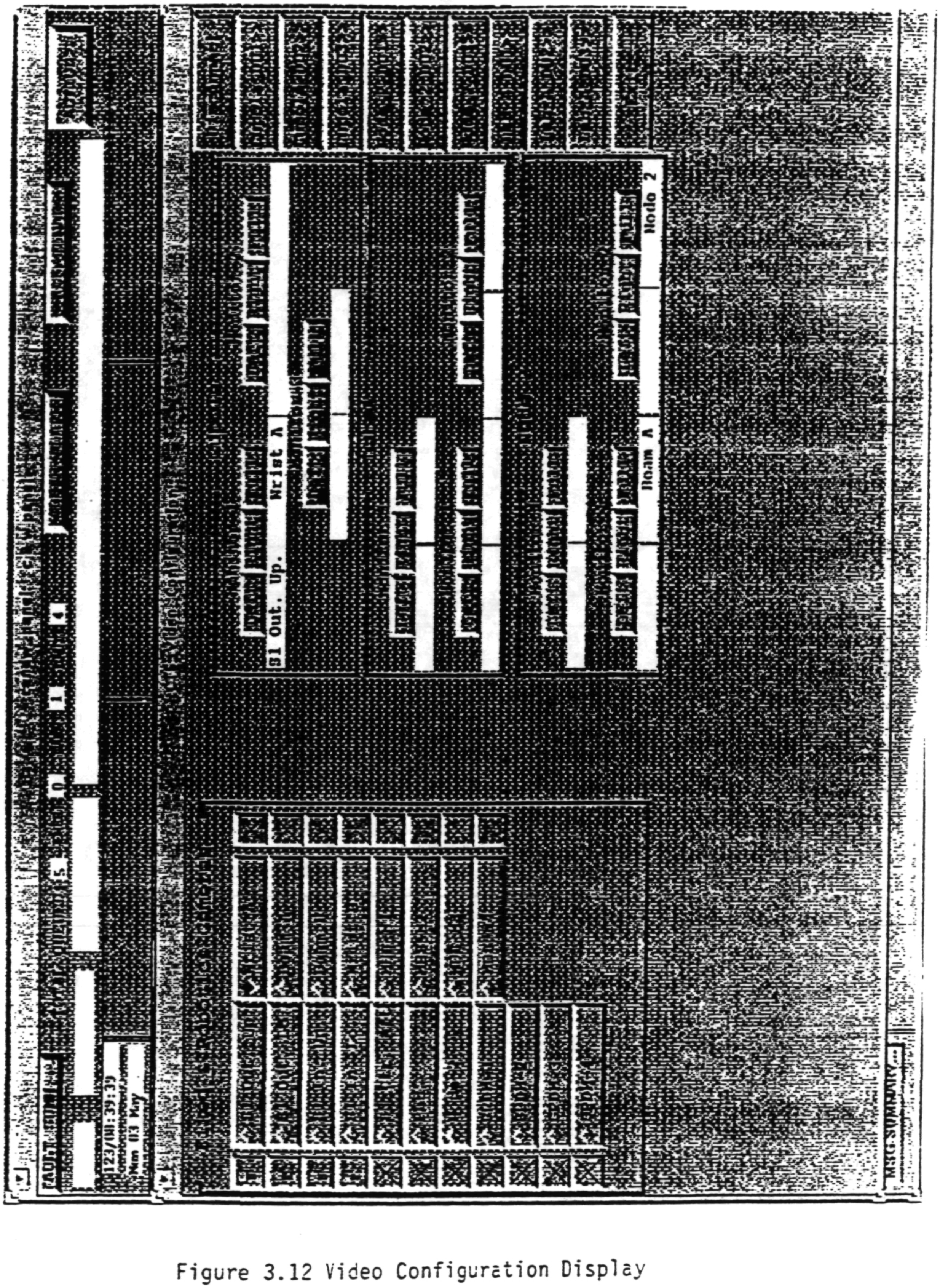

Figure 3.12 Video Configuration Display

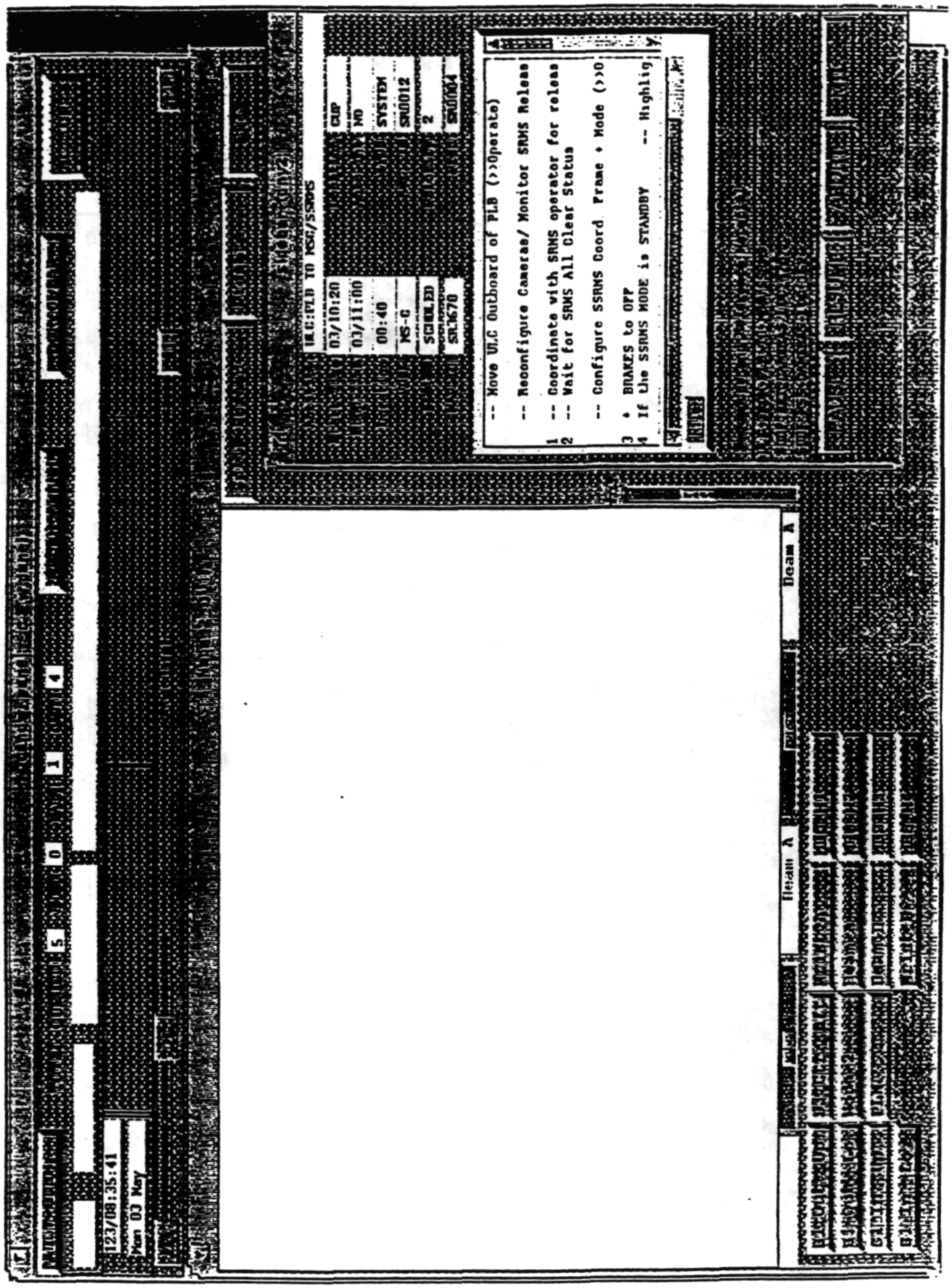

Figure 3.13 Camera Control

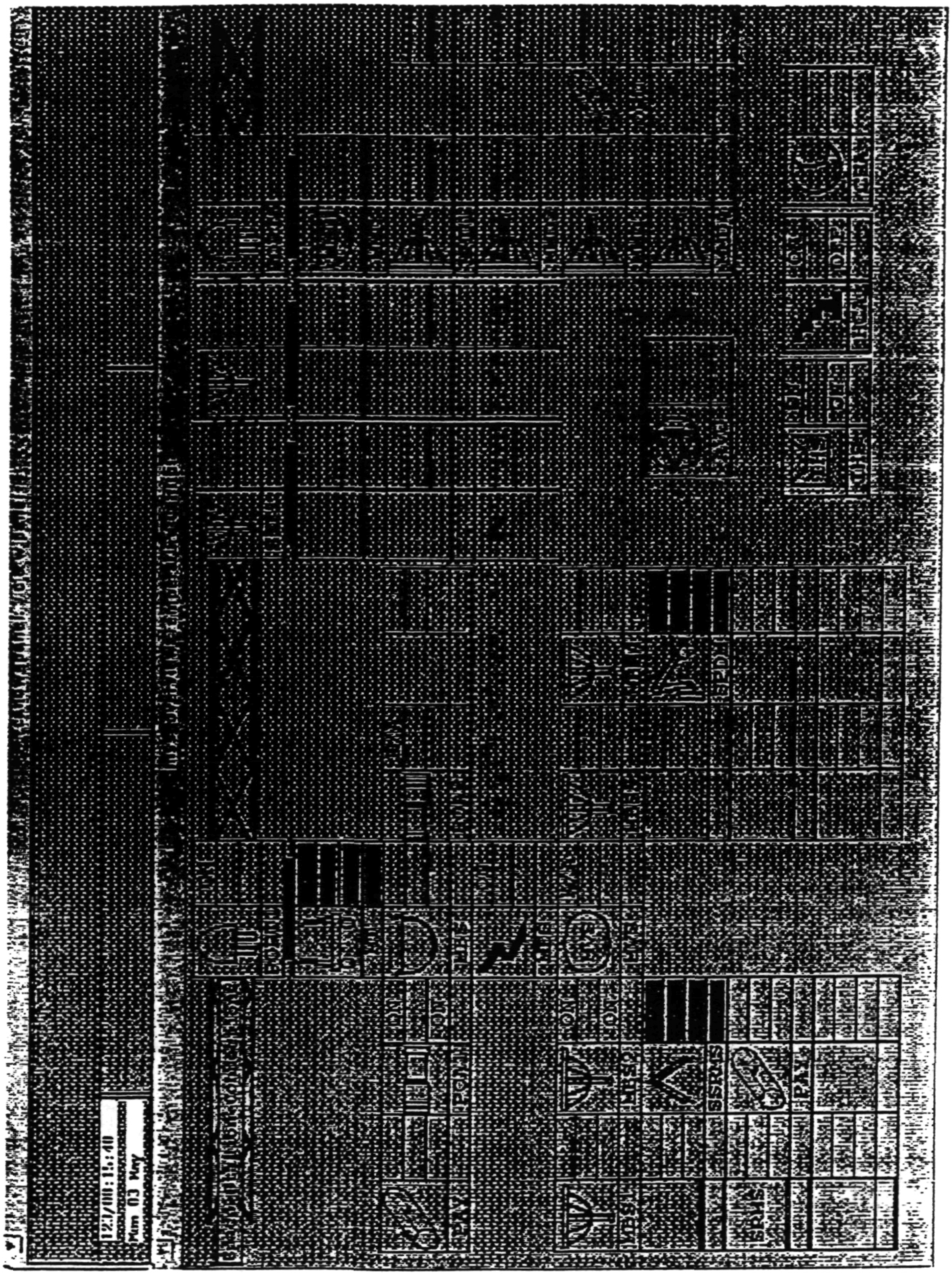

Figure 3.14 Robotic Operations Main Menu

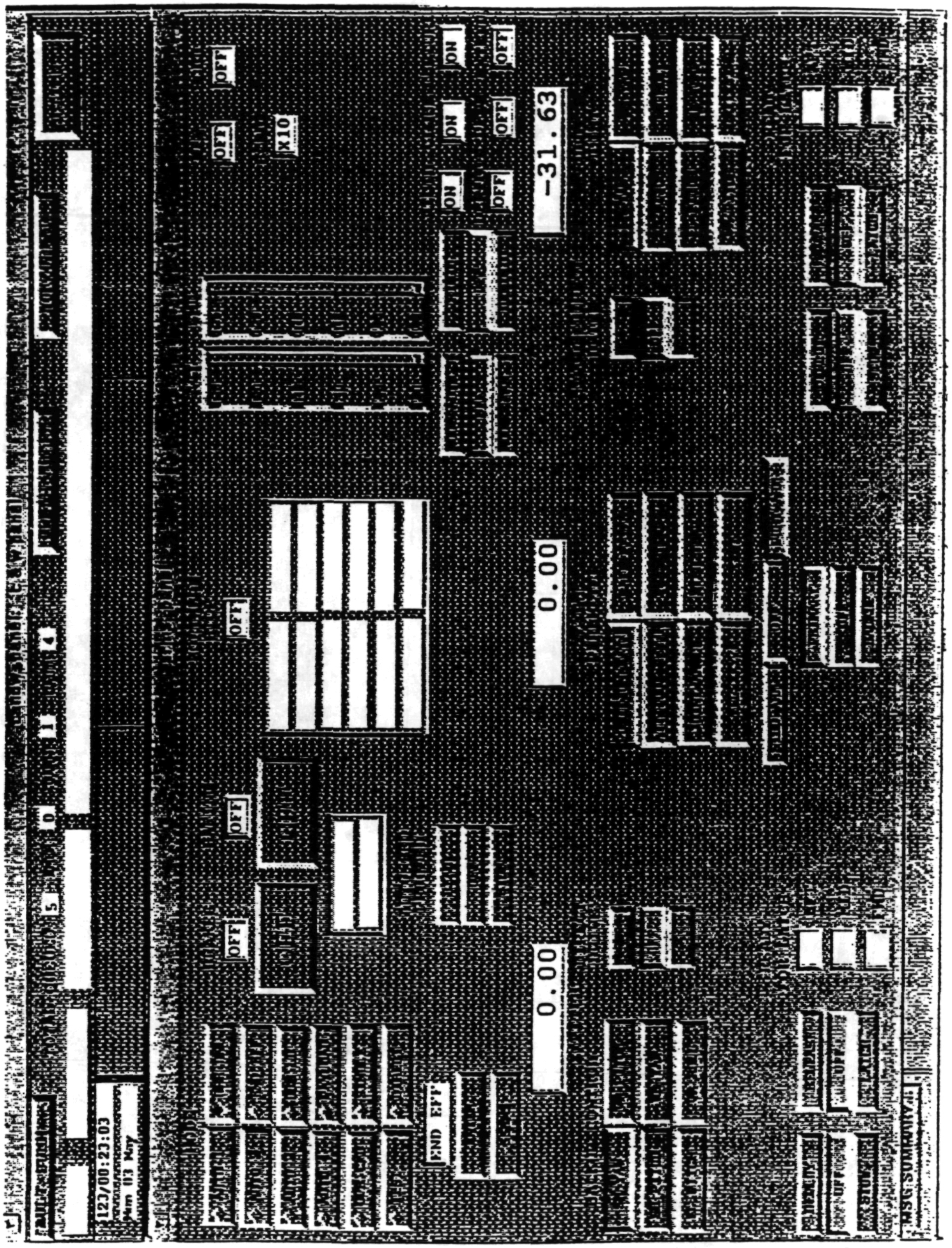

Figure 3.15 Space Shuttle Robotic Arm Operations Display

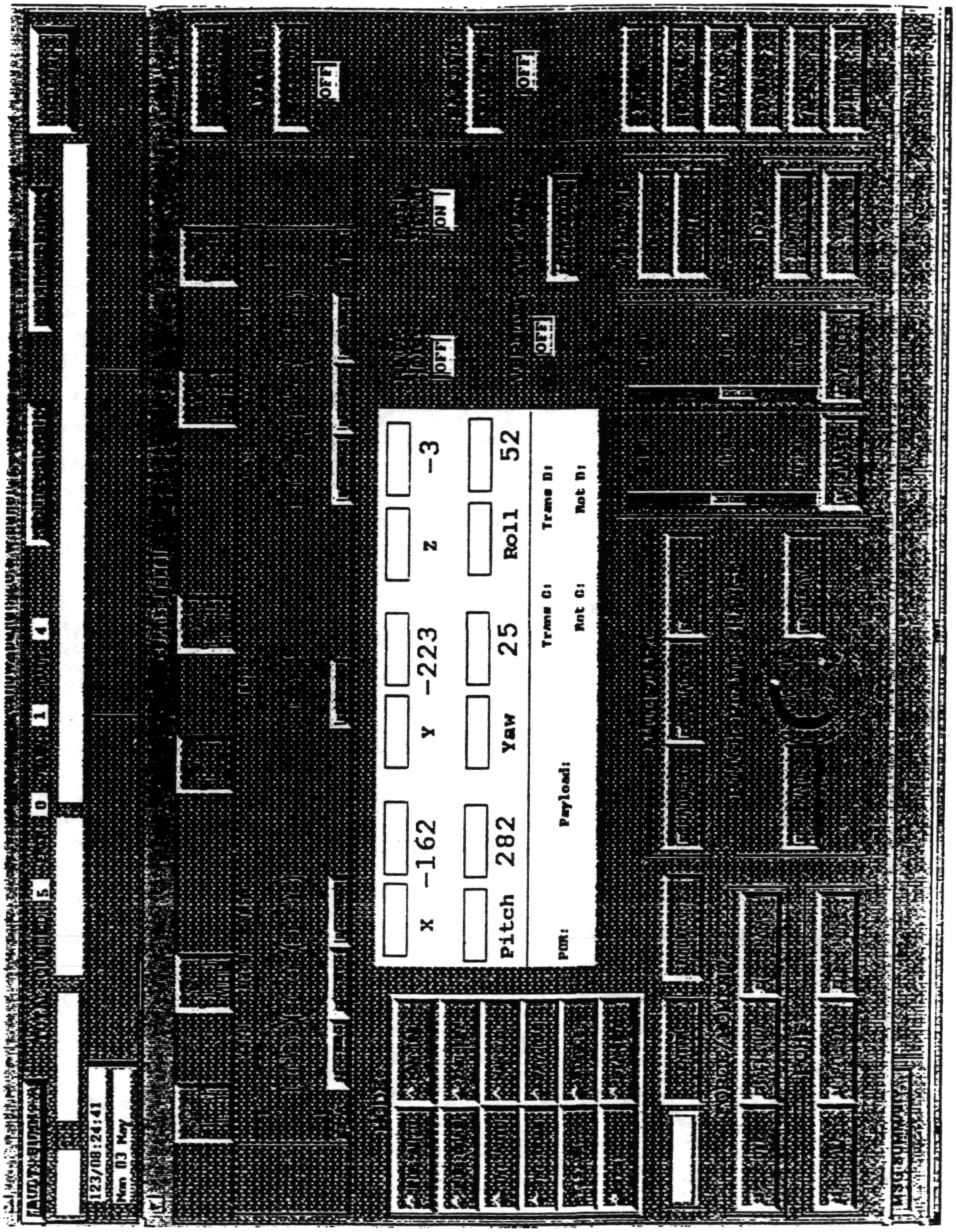

Figure 3.16 Space Station Robotic Arm Operations Display